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Horizontal Alignment of Drip Lines Relative to Beds in SDI: Effects on Cotton Growth and Yield

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Abstract. A subsurface drip irrigation system with drip lines below alternating furrows was used to establish three irrigation treatments designated as HW, MW, and LW applied 1.0*PET, 0.6*PET, and 0.5*PET. By mid July a pattern of alternating rows with tall and short plants (row type) was visible. A study was initiated to quantify the variability of cotton growth and yield between adjacent rows. The position of irrigation laterals and flow rate of emitters was measured. Plant size and lint yield were measured in the two row types. The drip line moved closer to one of the adjacent beds as distance increased from the header line. Water flow was uniform among emitters along the drip lines. Plant height decrease along the row was greater for short rows rather than tall rows. Cotton yields were higher in tall rows than short rows. Short rows in all water levels had a decreasing yield trend with distance from the header line. Tall row yields increased down the row in the LW and MW water levels, but decreased in the HW water level. Difference in plant height and yield between row types was attributed to water supply differences caused by drip lines being closer to tall rather than short rows. The simultaneously decreasing trend of plant height in all water levels in both row types and HW treatment yield were likely caused by reductions in soil nutrient levels.

Keywords. Drip irrigation, emitters, irrigation, and flow rate

Introduction

The use of subsurface drip irrigation (SDI) is increasing in the Southern High Plains area of Texas as the supply of ground water gradually declines and well output decreases. Subsurface drip irrigation offers a number of potential benefits including increased efficiency of water use in crop production by precision placement of irrigation water in the crop root zone and greatly reducing water evaporation loss (Bucks and Davis, 1986; Ayers et al. 1999).

The SDI systems are usually installed on smaller fields than previous irrigation systems which initially used furrow irrigation and later center pivot systems to apply water. The smaller areas provide the opportunity to meet crop irrigation requirements with reduced water supplies. The irrigation laterals are normally installed underneath alternate furrows to decrease the cost of the SDI system installation. This pattern of installing drip line laterals results in water being applied to only one side of each bed with the opposite side remaining relatively dry. This drip line arrangement requires precise horizontal placement of laterals equidistant from each bed to facilitate equal water supply to both beds. When the lateral placement is not correctly positioned non-uniform application of water can occur and crop growth may be affected.

This situation occurred in an irrigation study conducted in the research field of the USDA-ARS, Plant Stress and Water Conservation Laboratory, Lubbock, TX during the summer of 2003. This was the second year of irrigating with an SDI system having the drip line arrangement discussed above. During 52 days from 1 July through 21 August no rain fell. By mid July it was observed that the plant size of adjacent rows was uneven which created a pattern of alternating tall and short rows across the entire study area.

Our first response was to alter plant data measurements to include both short and tall plant rows in all plots. Infrared thermometers used to schedule irrigation were checked and when necessary moved to a tall row in each plot. Then data collection was initiated to document and identify the cause for uneven plant growth in adjacent rows. The objective of this report is to analyze and interpret the data collected for the purpose of documenting and describing the effect of miss-alignment of drip lines in relation to the adjacent rows on cotton development and lint yield.

Procedure

Prior to planting three 0.5 in irrigations were applied and an additional 0.5 in irrigation during emergence. On 8 May 60 kg N/ha was applied at the side of each bed using chisels. Another 15 kg N/ha was injected through the SDI system on 5-7 August. The study was planted on 14 May 2003 with the variety Paymaster 2326 BGRR. Three irrigation scenarios designed to supply water ranging from limited to full irrigation were used by changing the irrigation frequency at different growth stages according to cotton's yield sensitivity to water stress during each stage.

The relative water supply levels and their designations were: LW- 0.33*PET, MW-0.66*PET, and HW-1.00*PET. The BIOTIC (Upchurch, et al. 1996) irrigation timing protocol was used to time irrigation events. The irrigation timing procedure, which also included a protocol for substituting rain for irrigation (Wanjura, 2003), was programmed into a Campbell Scientific 23X data logger. Irrigation was started on 8 July (DOY 189) when seedlings had grown sufficient leaf area to provide an accurate measurement of canopy temperature. A 5 mm irrigation was applied in response to each irrigation signal through the SDI system. Irrigation drip lines with 0.23 gph emitters spaced 24 in apart (Netafim Typhoon 875) delivered water along the row length under a 10 psi head. Drip lines were located beneath alternate furrows to irrigate the adjacent beds.

The position of irrigation laterals was checked in two irrigation zones by removing the soil above the drip line at 8, 38, 84, 130, and 160 m from header-line end of 168 m rows. The vertical position of the lateral below the top surface of the adjacent beds and the horizontal distance from the lateral to the plants in the east adjacent row was measured. Flow rate of emitters was also measured in each uncovered row at the five locations. Flow rates were measured while either 2, 15, or 21 irrigation zones were being irrigated. Zone valves were opened and the irrigation pump was started. Sufficient time was then allowed to fill all active irrigation zones prior to measuring emitter flow during a 15-minute period.

Biomass samples were collected from the south half of rows (nearest the header) where canopy leaves were mostly green in contrast to being more senescent in the remaining row length. Ten plants each from rows with either short or tall plants (row type) were harvested on 16 September in all plots. Crop reflectance was also measured using a multispectral radiometer (Model MSR16, Cropscan, Inc.) positioned above the canopy at a sufficient height to view a circular area whose diameter was 75% of the canopy width.

On 1-3 October plant height and main stem node measurements were made in the three water levels in replications 2 and 3 in one row of each row type at eleven row locations beginning 11 m from the header-line end. Ten plants were tagged and measured at each row location and bur cotton from the same plants was harvested on 20 November 2003. Bur cotton yield variation along the row length was estimated from the eleven row locations.

Hand-harvest yields were also taken from 2 m row lengths of both row types from the four replications of the water use efficiency study on 19 November. The hand-harvest areas were 2 m lengths of rows 2, 3, 6, and 7 of each plot. Four harvest areas were located 23, 69, 99, and 145 m from the header-line end.

One m soil cores samples were taken in a dry furrow of each plot. The locations designated as south, middle, and north were 38, 91, and 130 m from the header-line end. Soil cores were taken on 3 June and 3 December for use in calculating seasonal water use. The cores were sub-divided into 20 cm increments and the 20-40 cm increment from the 3 December sampling were also used for soil nutrient analysis. The 20-40 cm increment included the depth position of the irrigation drip line in the adjacent furrows.

Results

The sequence of time thresholds used to control irrigation of the three irrigation treatments during each growth stage are summarized in Table 1. No irrigation was applied during growth stage 1 because 14.6 cm of rain during this period (DOY 140 to DOY 189) provided adequate soil moisture. Time thresholds for growth stages 3 and 4 were set at the most favorable levels for each irrigation supply level since both are sensitive to yield.

The spacing between rows was 1 m with the drip line located below the furrow of alternate rows. The lateral position in relation to the beds is shown for five locations in each measured furrow, Table 2. For the 20 locations shown in the table, six drip lines were within 2 cm of being at the exact midpoint between the two rows. Lateral locations at 130 and 160 m showed the largest deviation from the midpoint between the rows. Vertical position of laterals ranged from 33 to 41 cm below the top of beds.

Flow rates of single emitters were measured at the same row locations while different numbers of zones were being irrigated, Table 3. Flow along the length of the laterals was uniform and there was no difference in the average flow of emitters in the same lateral while the total flow in the irrigation system changed as the number of zones irrigating varied from 2, 5, and 21. Average flow rates of the two laterals in zone 31 were lower than in zone 29.

Table 1 Time thresholds for controlling irrigation during five cotton growth stages in 2003

Growth Stage	Growth Stage	Starting Date	Irrigation Level LW (0.33*PET)	MW (0.66*PET)	HW (1.0*PET)
			--- Time Thresholds, hours [1] ---		
1	Emergence	None	NI [2]	NI	NI
2	First Square	8 July (DOY13)	7.5	6.0	3.0
3	First Bloom	15 July (DOY 196)	6.0	5.5	3.0
4	Peak Bloom	29 July (DOY 210)	6.0	5.5	3.0
5	Boll Maturity	12 August (DOY 224)	NI	7.5	5.5

[1] Time is counted for daytime periods when canopy temperatures are > 28 °C , and net radiation is > 200 W m^{-2}

[2] NI indicates no irrigation occurred during this growth stage

Irrigation and total water values for the three water level treatments are shown in Figure 1. Assuming that the HW total irrigation of 33.6 cm was 100% of PET, the total irrigations applied to LW and MW treatments of 20.1 and 23.1 cm represented 69% and 60%*PET. The intended level for LW was 33% of PET. Based on the in-season irrigation amounts of 28.5, 18.0, and 15.0 cm for HW, MW, LW treatments, these amounts represent 100%*PET, 63%*PET, and 53%*PET. The in-season irrigation application of the MW treatment closely approximated the intended level of 66%*PET; however, LW received almost double the intended level of 33%*PET.

The total number of irrigations applied in response to irrigation signals produced by their assigned time threshold values was 30, 36, and 57, respectively, for the LW, MW, and HW treatments. The total number of days in the irrigation period was 35, 45, and 81 for the LW, MW, and HW treatments. Thus the LW, MW, and HW treatments received irrigations on 86, 80, and 70% of the total days in their respective irrigation periods. The differences in the total number of days in the irrigation period among treatments resulted from the combination of assigned time threshold values during growth stages 2 to 5. Irrigation of the LW treatment was terminated at the beginning of growth stage 5, after boll setting was completed while MW and HW irrigation continued at rates controlled by their time threshold values required for irrigation signals.

Table 2 Horizontal and vertical positions of drip line laterals at five locations along the row for two furrows in two irrigation zones

Distance from end of row, m	Furrow between beds	Lateral position, cm		Furrow between beds	Lateral position, cm	
		From bed 3 plants	Below top of beds		From bed 5 Plants	Below top of beds
			Zone 29			
8	3-4	41	33	5-6	43	41
38	3-4	46	36	5-6	51	41
84	3-4	48	36	5-6	51	41
130	3-4	38	33	5-6	36	38
160	3-4	36	38	5-6	38	41
			Zone 31			
8	3-4	43	33	5-6	43	36
38	3-4	48	33	5-6	53	36
84	3-4	43	36	5-6	48	38
130	3-4	28	33	5-6	23	41
160	3-4	18	38	5-6	20	41

The plant characteristics summarized in Table 4 include both vegetative and lint yield parameters. Plant height was smaller in the short rows than tall rows in all water levels. Main stem node numbers were not affected by row type or water level. Leaf area per plant was significantly different in the two row types for all water levels. Boll maturity tended to be highest in the short rows of all water levels, with the differences being largest in the high water level. All plant character differences between the two row types are consistent with the assumption that short rows received less irrigation because the drip line was located closer to the tall rows.

Plant heights were measured in each water level of replications 2 and 3 at eleven locations along the row. Plant height decreased linearly from the header-line end of rows in all water levels for each row type, Figure 2. The regression coefficients for plant height in both row types indicated that rate of plant height decrease was greater for the short rows than the tall rows in each water level. Regression coefficients for all plant height equations in Figure 2 were significantly different from zero. The differences in rate of plant height decline caused height differences between the row types to be greatest and most noticeable at the end of rows. The average plant height was 72, 74, and 77 cm for the LW, MW, and HW water levels, respectively. Plant height for short and tall rows averaged across water levels was 68 and 80 cm, respectively.

Table 3 Emitter flow rates at five locations along the row for drip line laterals in two zones while either 2, 15, or 21 zones are irrigating

Distance from end of row, ft	Furrow between beds	Flow rate, ml/min			Furrow between beds	Flow rate, ml/min		
		Number of zones irrigating				Number of zones irrigating		
		2	15	21		2	15	21
				Zone 29				
8	3-4	21.33	20.00	23.67	5-6	20.33	18.33	22.00
38	3-4	22.33	22.67	21.33	5-6	22.33	21.67	21.00
84	3-4	17.67	22.00	22.00	5-6	18.67	19.33	24.00
130	3-4	23.00	21.33	24.33	5-6	15.33	20.67	22.67
160	3-4	22.00	21.33	20.33	5-6	20.67	20.00	19.67
Average		21.3	21.5	22.3		19.5	20.0	21.9
				Zone 31				
8	3-4	19.67	17.67	18.67	5-6	18.33	17.33	18.33
38	3-4	20.33	19.00	19.33	5-6	20.67	20.67	20.00
84	3-4	18.67	19.67	19.33	5-6	20.00	19.33	19.00
130	3-4	19.33	20.00	18.00	5-6	19.00	19.67	18.67
160	3-4	19.33	19.67	20.00	5-6	19.33	20.00	19.67
Average		19.5	19.2	19.1		19.5	19.4	19.1

A change in horizontal location of the buried drip line along the row so that it is closer to the tall row of plants should have provided more water to tall rows and less to the short rows. Increased water available to tall rows is the likely explanation for plant height being greater in tall rows than short rows. The decline in plant height from the header-line end of both row types suggests that water supply was not the causative factor for height decline along the row since the same quantity of water should have been supplied uniformly along the row. High water availability to tall rows should have produced uniform plant height along the row. The emitter flow rates in Table 3 do not indicate differences in flow along the row length. The field was laser plane leveled in 2002, which could have changed the soil characteristics in the upper-most region of the soil profile if there was a uniform displacement of soil in the row direction.

Yield trend along the 11 within row locations was estimated by hand harvesting bur cotton on 20 November, Figure 3. Bur cotton yield varied in both row types among the row locations in each water level. Average bur cotton yields from short and tall rows were 3,252 and 3,709 kg/ha in the LW treatment, 3,474 and 3,918 kg/ha in the MW treatment, and 3,727 and 4,393 kg/ha in the HW treatment were significantly different. The short rows displayed a decreasing yield trend in all water levels and the regression-line slopes were significant in the MW and HW levels.

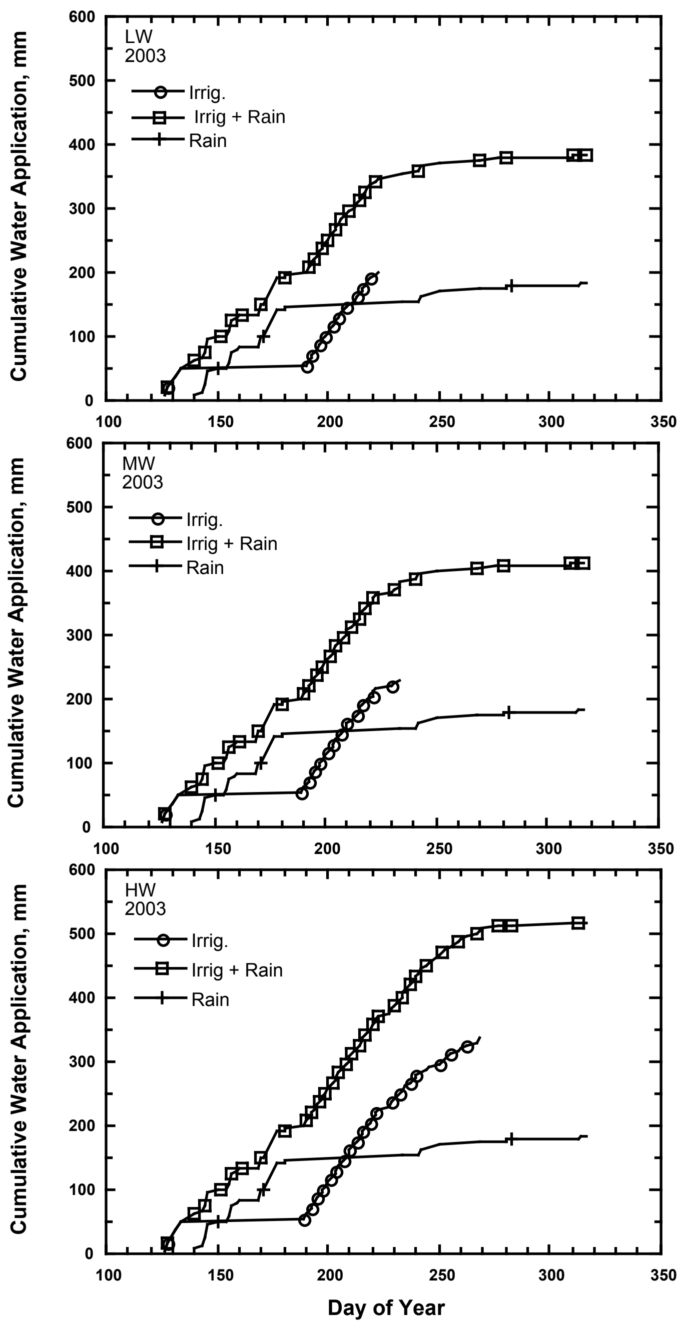

Figure 1 Irrigation and total water applied to LW, MW, and HW irrigation treatments, 2003

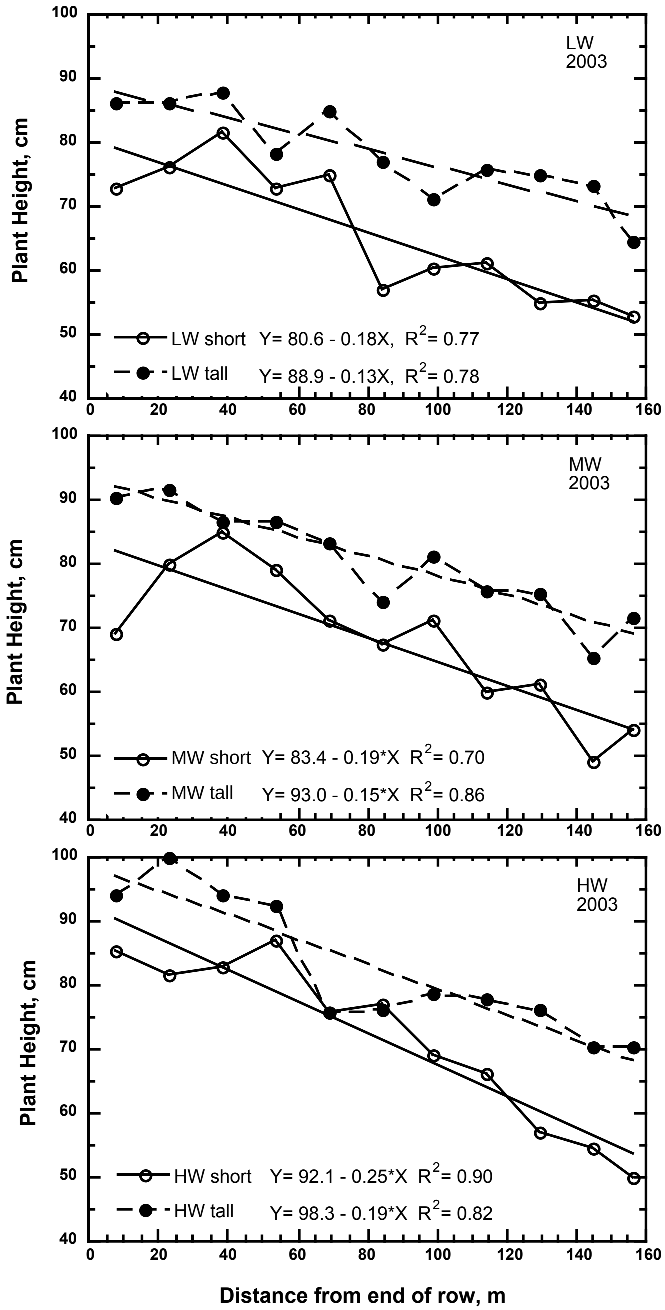

Figure 2 Plant height variation along the row for two row types, October 1, 2003.

Table 4 Plant biomass characteristic values on 16 September 2003

Plant Character	Irrigation Level (0.33*PET) LW		(0.66*PET) MW		(1.0*PET) HW	
	Short	Tall	Short	Tall	Short	Tall
Plant height, cm	83	88	80	87	81	89
Main stem nodes, no.	21	22	22	23	22	23
Leaf area, cm^2/ plant	1927	2226	2149	2574	2220	3245
Boll maturity, %	71	68	62	59	49	40
Total bolls, no./plant	6.8	6.6	7.8	8.3	8.3	10.2

Yields in tall rows had significant positive trends with decreasing slopes between the LW and MW water levels, and a significant negative trend in the HW water level.

The average bur cotton yield trend (mean of short and tall rows) was significantly negative for HW treatment (-4.29 kg/row m), non-significantly negative for MW (-1.13 kg/row m), and non-significantly positive for LW (0.74 kg/row m). The average HW treatment yield progressively decreased along the row while the LW and MW average yields were unaffected by within row location. Under HW irrigation unknown factor(s) caused a negative yield trend, under MW irrigation increased water availability (tall rows) produced a positive yield trend and reduced water availability had a negative yield trend, and under slightly more limiting irrigation LW increased water availability (tall rows) resulted in a positive yield trend while decreased water availability had no yield effect.

The lint yield hand-harvest from the entire study from four locations within the row and the range of the eleven locations used for plant height and bur cotton yield analysis are shown in Figure 4. The lint yield trend along the row agreed with those for bur cotton (Figure 3). Lint yield trend lines had higher R^2 values than those for bur cotton in all water levels; however, the regression slopes were non-significant for all treatments.

Soil nutrient analysis in Table 5 indicates that the content of nitrogen in the 20-40 cm depth below the furrow was highest in either the south or middle row locations and lowest at the north location at the end of the season. Phosphorous, potassium, and magnesium were significantly highest at the south location. Calcium was significantly lower at the south location and trended higher at the middle and north locations. A caliche layer is usually located below the soil surface and the higher calcium contents at the middle and north locations could be associated with the laser plane leveling which moved top soil from the north to the south end of rows. Amounts of other minor nutrients were not different among row locations. The content of nitrogen, phosphorous, and potassium was lowest at the north end of rows which suggests that limiting soil nutrients may have caused the decline of plant height and yield along the row.

Different plant responses down the row were caused by irrigation level and other unknown factor(s). The response of the HW treatment was consistently negative for plant height and bur cotton yield with the short rows decreasing more than tall rows. The difference between row types can be attributed to water supply differences caused by drip lines being closer to tall than short rows, but the simultaneous decrease of plant height and yield in both row types of the HW treatment was probably caused by declining soil nutrient levels. There were two gradients, one along the row associated with declining soil nutrients and between rows by changes in the horizontal position of irrigation laterals.

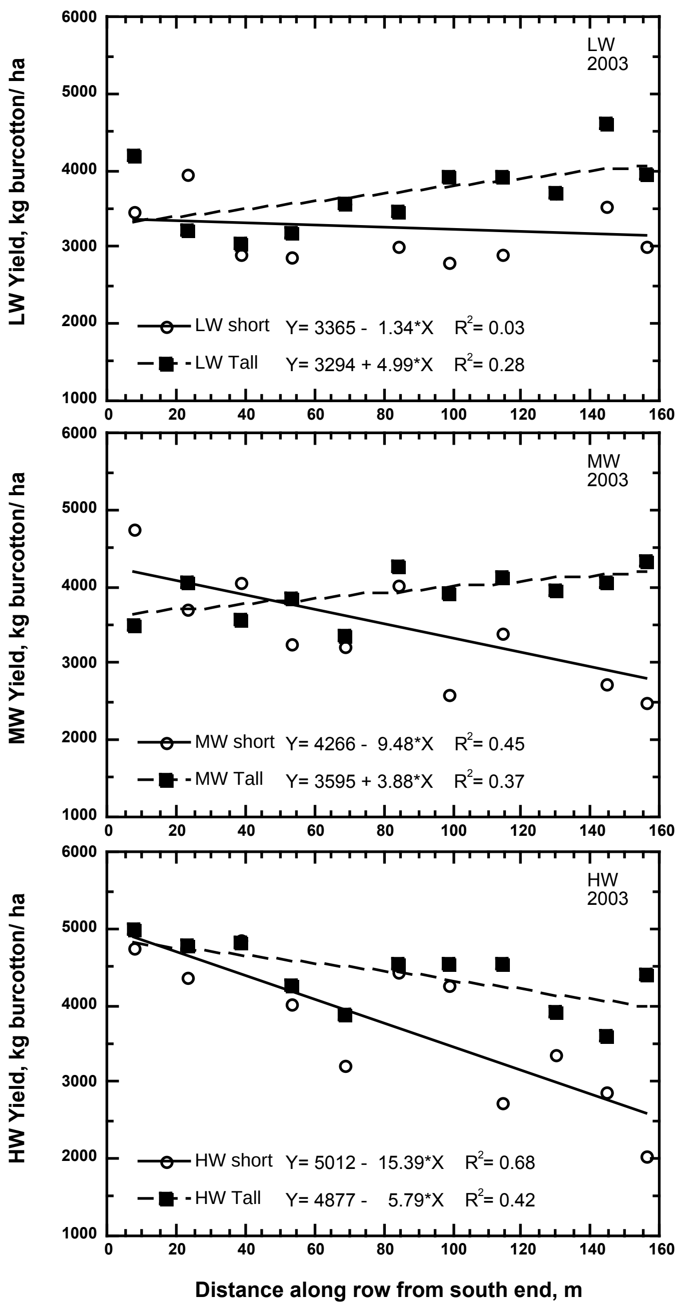

Figure 3 Yield variation along the row length for two row types and three water levels, November 20, 2003.

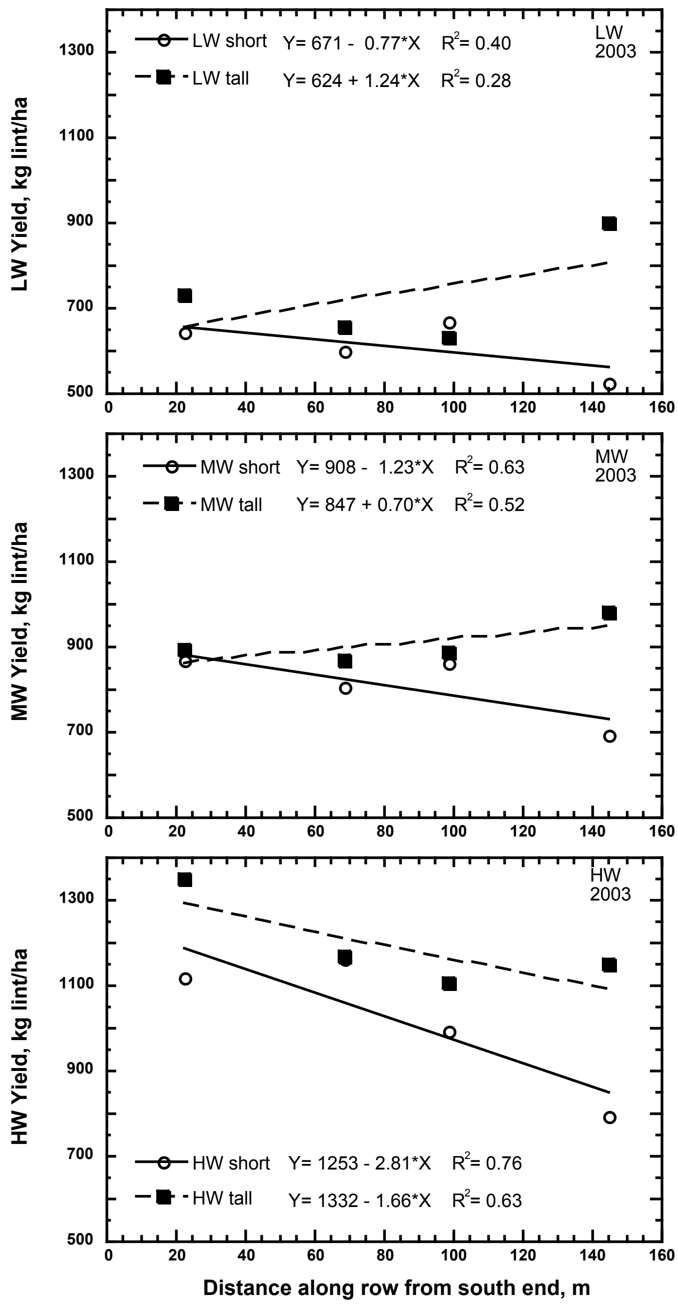

Figure 4 Yield variation along the row length at four locations for two row types and three water levels in water use efficiency study, November 19, 2003.

Table 5. Soil nutrient sampling in the 20-40 cm depth increment, 2 December 2003.

	Row Location		
Nutrient Analysis	South	Middle	North
NO_3- N kg/ha	7.4 a,b [1]	9.4 a	4.9 b
Phosphorous, ppm	38.3 a	5.4 b	6.3 b
Potassium, ppm	405 a	302 b	342 b
Calcium, ppm	1409 b	1827 a	1985 a
Magnesium, ppm	492 a	294 b	299 b
Sodium, ppm	223 a	143 a	158 a
CEC, meq/100 g	13 a	14 a	13 a
Zinc, ppm	0.7 a	0.6 a	0.5 a
Iron, ppm	9.0 a	7.8 a	7.0 a
Manganese, ppm	5.4 a	4.3 a	4.1 a
Copper, ppm	0.5 a	0.5 a	0.7 a
Soil pH	7.6 a	7.7 a	7.8 a
Organic matter, %	0.6 a	0.6 a	0.6 a

[1] Values on the same row followed by a common letter are statistically equal at the 0.05 level of probability according to the Tukey-Kramer test.

Conclusions

Three irrigation treatments identified as HW, MW, and LW applied 1.0*PET, 0.63*PET, and 0.53*PET through an SDI system with drip lines located below the furrows of alternate beds. The horizontal position of the drip line moved closer to one bed as distance increased from the header line end creating alternating rows of tall and short plants. Plant height decreased linearly along the row in all water levels for each row type, with short row decreases being greater than for tall rows. Measured water flow was uniform among individual emitters along the length of two drip lines. Tall row yield trends were significantly positive with declining slopes between LW and MW treatments, but the trend for the HW treatment was significantly negative. Difference in plant height and yield between row types can be attributed to water supply differences caused by laterals being closer to tall than short rows. The simultaneous decreasing trend along both row types of all treatments for plant height and the HW treatment yield was likely caused by decreasing soil nutrient levels from south to north.

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Appendix or Nomenclature

This optional section can include lists of nomenclature or abbreviations, reference data, or tables that are too long to include in the body of the article.